

# Pc-scale study of Radio galaxies & BL Lacs

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## Abstract

We study two aspects of the differences between Active Galactic Nuclei (AGN) of the two Fanaroff-Riley types in order to investigate the causes of the F–R divide. We (a) contrast the properties of the optical cores in beamed and unbeamed AGN of the two types, incorporating Hubble Space Telescope measurements of the unbeamed objects, and (b) contrast the nuclear magnetic field geometry of the beamed AGN of the two types using Very Long Baseline Polarimetry.

*Key words:* Galaxies: Active, Galaxies: Nuclei, BL Lacertae objects, Polarimetry

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## 1 Introduction

Radio-loud AGN are broadly thought of as having two Fanaroff-Riley types, with the low radio-luminosity type I (FRI) objects exhibiting diffuse radio jets and the high-luminosity type II (FRII) objects having collimated jets and terminal hotspots. In their discovery paper, (?) had found the luminosity divide to be at  $2 \times 10^{26} \text{ WHz}^{-1}$  at 178 MHz. In the framework of the standard Unified Scheme (US), FRI and FRII radio galaxies represent the parent populations of BL Lacs and radio-loud quasars, respectively (?). It follows that a ubiquitous obscuring torus is *required* in the FRII population but not in the FRI population. Adopting this framework, we will refer to FRI radio galaxies and BL Lacs as the “FRI population” and FRII radio galaxies and quasars as the “FRII population.” To address the origin of the F–R dichotomy, we will look at differences in the properties of (i) the pc-scale optical cores and (ii) the magnetic (**B**) field geometry in the pc-scale radio jets of the two populations (we assume  $H_o=75 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ,  $q_o=0.5$ ).

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## 2 The pc-scale optical cores in radio galaxies

The Hubble Space Telescope (*HST*) has revealed unresolved optical cores in the centres of a majority of FRI and FRII radio galaxies (?). These authors suggest that the core emission in the FRIs and some FRIIs is optical synchrotron radiation. Here we examine the evidence that the optical core luminosity,  $L_o$  ( $K$ -corrected), is orientation dependent by searching for correlations with the radio core prominence,  $R_c = S_{core}/S_{ext}$  (at an emitted frequency of 5 GHz), which is a statistical indicator of relativistic beaming (?) and therefore of orientation. This comparison is plotted in Figs. 1 and 2 for the FRI and FRII populations, respectively. For the beamed objects (*i.e.*, BL Lacs and quasars) we have taken the optical core luminosity to be the total optical luminosity, assuming the core overwhelms the host galaxy emission.

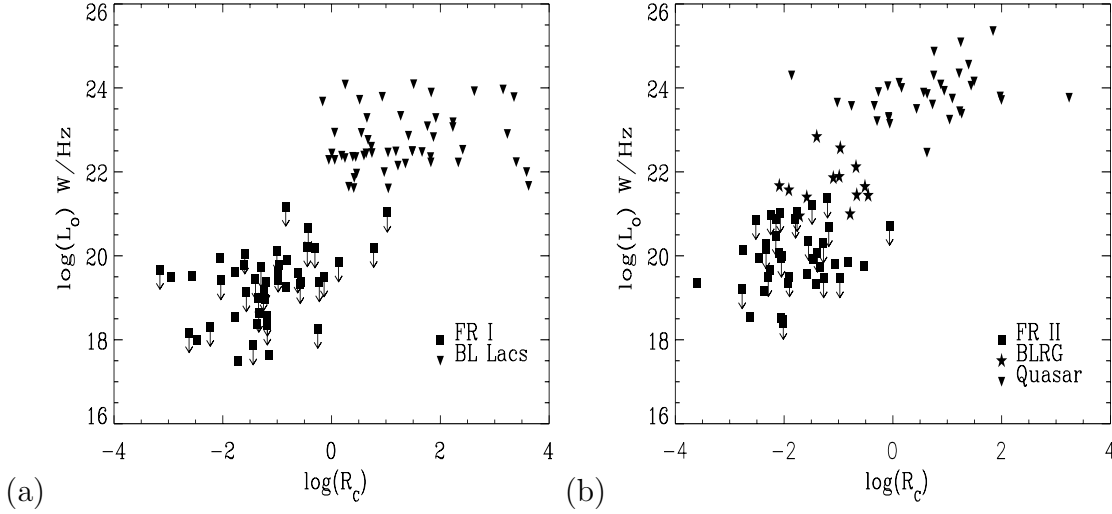


Fig. 1.  $R_c$  vs. optical core luminosity,  $L_o$ , for the (a) FRI population and (b) FRII population. We use  $R_c$  as a proxy for orientation. Arrows denote upper limits.

$L_o$  is significantly correlated with  $R_c$  (orientation) for the FRI radio galaxies alone ( $> 0.005$  level, Spearman rank correlation test), as well as for the whole FRI population ( $> 0.0005$  level). In the FRII population, the narrow-lined FRIIs do not show any correlation by themselves, although a significant ( $> 0.0005$  level) correlation exists for the broad-line objects, *i.e.*, Broad-Line Radio galaxies (BLRGs) and quasars (as well as for the FRII population as a whole). This is consistent with there being obscuration effects by a torus in the FRIIs but not in the FRIs. We note that optical cores have been detected in *all* the BLRGs observed (where the US predicts no obscuration by the torus), again consistent with this idea. We attempted to fit a model in which the observed optical emission ( $L_o$ ) is due to contributions from a relativistic optical synchrotron jet ( $L_{jet}$ ) and a thin accretion disk ( $L_{disk}$ ) using the equations :

$$\log L_o = \log[\delta^p * L_{jet}^{int} + L_{disk} * \cos(\theta)]$$

$$\log R_c = p * \log \delta + \log R_c^{int}; \text{ int =intrinsic}$$

Here  $\delta$  and  $\theta$  are the Doppler factor and inclination, and  $p=(2+\alpha)$  or  $(3+\alpha)$ , depending on whether the jet is continuous or blobby ( $\alpha$ =jet spectral index).

In the best-fit models, the intrinsic (*i.e.*, unbeamed) jets were only an order of magnitude more luminous in the FR II population, while the FR II accretion disks were more luminous than the FRI disks by three orders of magnitude. However, there are some caveats in this analysis: (i) the BL Lacs show a large scatter, which could be due to variability, (ii) there is a paucity of FRI objects at intermediate values of  $R_c$ , (iii) the  $L_o$  values for the BL Lacs and quasars are total values, and include the host galaxy contribution, and (iv) the beamed and unbeamed objects were not matched in redshift and extended radio luminosity.

### 3 The pc-scale **B** field geometry in BL Lac objects

VLBI polarimetry has shown that a majority of radio-loud quasars have jet **B** fields aligned with the local jet direction, while most BL Lacs have transverse jet **B** fields (?). Most of these BL Lacs were radio-selected BL Lacs (RBLs); subsequently, many more BL Lacs were discovered in X-ray surveys (X-ray selected BL Lacs, or XBLs). RBLs show greater radio core prominence, variability and optical polarization than XBLs (?), suggesting that RBLs are more beamed than XBLs. However, this cannot explain the differences in their spectral energy distributions (SEDs); most of the RBLs, like the core-dominated quasars (CDQs), have a synchrotron peak in the NIR/optical (low-energy peaked BL Lacs, LBLs) while the majority of the XBLs have this peak in the UV/soft X-ray (high-energy peaked BL Lacs, HBLs). Higher electron Lorentz factors and/or magnetic fields in HBLs have been suggested to explain the differing peaks (?). The CDQs, LBLs and HBLs form an SED sequence of increasing synchrotron peak frequency.

We explored if the **B** field geometry follows an analogous trend using observations of HEAO-1 XBLs using the NRAO <sup>1</sup> Very Large Baseline Array at 5 GHz (? , Kharb et al., in prep). Contrary to the tendency observed for the LBLs, the HBLs showed predominantly longitudinal **B** fields relative to the local jet direction (*eg.*, Fig. 2a). Fig. 2b shows a counter example: the HBL 1727+502, which has a transverse **B** field “spine” with longitudinal **B** field at the jet edges.

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There appears to be no straightforward interpretation of the  $\mathbf{B}$  field geometry trends in the beamed FRIs versus the beamed FRIIs within the simple US. Also, the  $\mathbf{B}$  field geometries in CDQs, LBLs and HBLs do not reflect the SED synchrotron peak sequence.

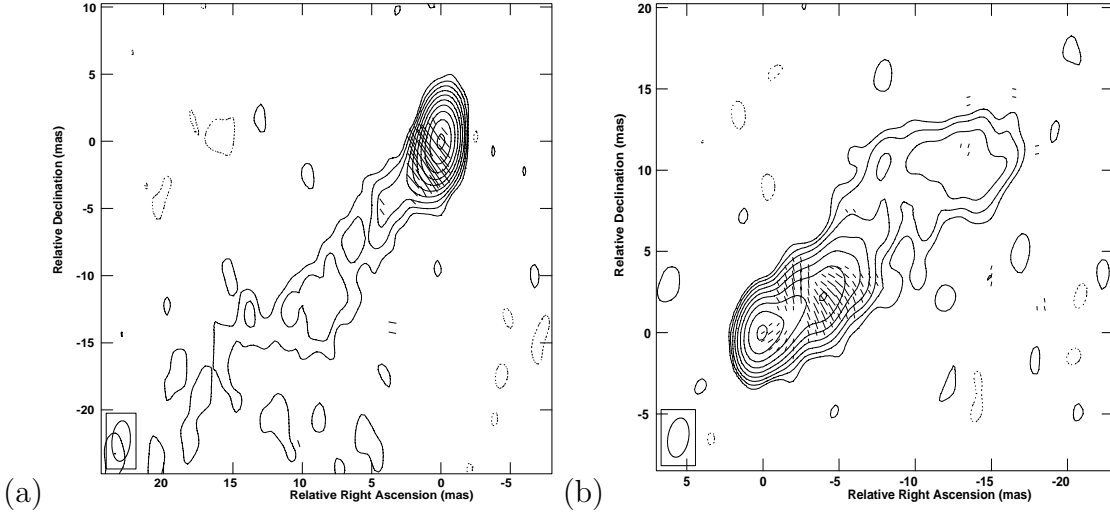


Fig. 2. Total intensity VLBI maps of the HBLs (a) 1215+303 and (b) 1727+502 at 5 GHz with polarization vectors superimposed. Contours are (a) -0.17, 0.17, 0.35, 0.70, 1.40, 2.80, 5.60, 11.20, 22.50, 45 and 90 percent of the peak brightness of  $231.1 \text{ mJy beam}^{-1}$ ,  $\chi$  vectors:  $1 \text{ mas} = 1.3 \text{ mJy beam}^{-1}$  and (b) -0.35, 0.35, 0.70, 1.40, 2.80, 5.60, 11.20, 22.50, 45 and 90 per cent of the peak brightness of  $64.2 \text{ mJy beam}^{-1}$ ,  $\chi$  vectors:  $1 \text{ mas} = 1.8 \text{ mJy beam}^{-1}$ .

#### 4 Conclusions

- (1) All BLRGs that have been observed with the *HST* have detected pc-scale optical cores, consistent with the US.
- (2) The optical core luminosity correlates significantly with  $R_c$  for the FRIs and BL Lacs, as well as the FRI radio galaxies alone. For the FRII population, only the BLRGs and quasars show a significant correlation while the narrow-line objects do not, consistent with obscuration effects by a torus in the latter.
- (3) Relativistic beaming alone can account for the variation in the optical cores of the FRI objects (beamed and unbeamed).
- (4) Modelling the optical emission as a combination of contributions from a jet and a disk suggests that the accretion disks of FRII objects are more luminous than those of FRI objects. This in turn suggests that the F–R division might be due to intrinsic differences on pc-scales.
- (5) The pc-scale jets of HBLs have predominantly longitudinal  $\mathbf{B}$  fields w.r.t. the local jet direction, in contrast to the tendency for LBLs.
- (6) The  $\mathbf{B}$  field geometries in CDQs, LBLs and HBLs do not reflect the SED synchrotron peak sequence of increasing frequency. Thus, no simple

conclusions can be drawn about the pc-scale  $\mathbf{B}$  field geometries and their connection with the F–R divide.